The Fate of Pyroclasts from Explosive Eruptions on Differentiated Asteroids. L. Wilson[1,2] & K. Keil[1] [1]Hawaii Inst. of Geophysics & Planetology, SOEST, Univ. of Hawaii at Manoa, Honolulu HI 96822, U.S.A. [2]Env. Sci. Div., Inst. of Environmental & Biol. Sci., Lancaster Univ., Lancaster LA1 4YQ, U.K. L.Wilson@Lancaster.ac.uk K.Keil@kahana.pgd.hawaii.edu

We show that the small grainsizes likely for pyroclasts erupted on Solar System bodies with zero atmospheric pressure tend to cause the lava fountains produced in explosive eruptions to be very optically dense. As a result, when explosive eruptions took place on differentiated asteroids with a wide range of sizes in early Solar System history, almost all of the pyroclasts were prevented from radiating heat to the surroundings and returned to the surface at magmatic temperatures, coalescing into lava ponds feeding flows. Typically, only ~1% of the deposited material would have consisted of recognizable pyroclastics - welded, partly welded or unwelded layers of pyroclastic glass beads of the kind found in some of the lunar samples. This helps to explain the apparent absence from meteorite collections of readily identifiable rocks sampling pyroclastic deposits.

In earlier work on volcanic activity on differentiated asteroids we identified likely ranges of sizes of dikes feeding surface eruptions, thus predicting likely magma eruption rates from fissure vents and the localized conduit sources into which they evolve by cooling as an eruption procedes [1]. We predicted that pyroclastic droplets produced by highly efficient fragmentation of basaltic magmas would have diameters in the range 30 to 4000 microns [2, 3]. Computation [3] of the launch speeds of droplets requires allowance for the fact that all droplets have a terminal fall velocity through the surrounding gas which is a function of their diameters and densities and also of the density and viscosity of the gas (both of which change as it expands and cools). It also requires consideration [3] of the range of angles from the vertical into which the erupted gas stream expands. A final correction is needed for the fact that, because their terminal velocity causes the larger pyroclasts to have a lower upward speed than smaller clasts, the kinetic energy which they forfeit is available to the gas and smaller clasts and leads to these components having a higher velocity than predicted from simpler theory [4].

Taking account of these factors we have computed eruption speeds of pyroclasts with the expected range of sizes in explosive eruptions on the differentiated asteroid 4 Vesta for a wide range of possible magma gas contents (Table 1). For these gas contents and likely eruption rates from fissure vents we have computed (Table 2) the number densities of pyroclasts in the resulting lava fountain and found how close a given clast must be to the outer edge of the fountain if it is to be able to radiate its heat to the surroundings. Clasts more that this critical distance Λ from the cloud edge will be screened by other clasts and can only exchange heat with one-another. They therefore land on the surface at magmatic temperatures and coalesce into lava ponds feeding lava flows. The conditions are similar to those inferred for the formation of lava ponds around the source vents of sinuous rilles on the Moon [5]. For all likely eruption rates on a Vesta-sized asteroid and for all but very hight volatile contents, much less than 1% of the area of the pyroclastic deposit consists of clasts that have had any opportunity to cool. Analogous calculations for a point source vent are given in Table 3 and show the same trend, though the cooled part of the deposit becomes significant when the volatile content exceeds a few 1000 ppm.

These results explain the absence of clearly identifiable pyroclastic materials [6] in the HED meteorites associated with 4 Vesta, given the evidence that Vesta was not a volatile-rich body [3]. Fissure eruptions on Vesta with gas contents of a few hundred ppm produced pyroclastic deposits in which less than 1% of the material was able to cool; furthermore, the internal structure of the asteroid evolved in such a way that large magma reservoirs, leading to protracted eruptions in which vent localization could occur, never developed [1]. We shall need many more HED meteorites than those yet available before we are statistically likely to find a sample of the cooled outer edge of a pyroclastic deposit.

Our calculations show that for smaller asteroids these lava fountain opacity effects are even more pronounced, with even less of the deposit consisting of cooled clasts. This result must be compounded with our earlier finding that all volatile-rich explosive eruptions on small asteroids launched pyroclasts at speeds exceeding the escape velocity, thus ensuring that no indication of their existance remains today. It is clear that only the very largest differentiated asteroids are likely to have been able to form only very minor amounts of readily recognizable pyroclastic deposits analogous to those on the Moon and Io.

References: [1] Wilson, L. & Keil, K. (1996) JGR 101, 18927. [2] Wilson, L. & Keil, K. (1996) EPSL 140, 191. [3] Wilson, L. & Keil, K. (1997) subm. to Meteoritics & Plan. Sci. [4] Wilson, L. & Parfitt, E.A. (1997) this vol. [5] Wilson, L. & Head, J.W. (1981) JGR 86, 2971. [6] Yamaguchi, A. personal comm.

Table 1. Values of u_m, the mean velocity in the vent of a choked flow of gas and pyroclastic droplets at pressure P_v (in kPa); u_g, the velocity of the gas phase after correction for finite terminal velocities of droplets and expansion of the gas to zero pressure; and u_d, the eruption velocities of droplets with diameters d = 30, 100, 300, 1500 and 4000 microns, for magma gas contents of n = 30, 100, 300, 1000, 3000 and 10^4 ppm. All velocities in m s^{-1}.

n	P_v	u_m	u_g	u_{30}	u_{100}	u_{300}	u_{1500}	u_{4000}
30	23.0	6.4	12.5	12.3	12.3	12.2	10.3	!
100	13.8	7.9	20.1	19.6	19.6	19.5	17.6	5.8
300	1.33	12.1	33.9	32.9	32.9	32.8	31.0	19.1
1000	0.23	21.7	61.6	59.9	59.9	59.8	57.9	46.1
3000	0.14	36.7	106.0	103.4	103.4	103.3	101.4	89.6
10000	0.11	65.7	193.5	189.2	189.2	189.0	187.9	176.0

Table 2. For 6 released magma gas contents, n in ppm and 4 magma eruption rates from a fissure vent, V/L in m^3 s^{-1} m^{-1}, values are given for the distance, Λ, in m, from the edge of the fountain at which the erupted cloud of pyroclasts becomes opaque to radiation transfer. For each n the gas eruption speed u_g in m s^{-1} and maximum droplet range D in km are given. For each Λ is given the value of F = [D-Λ]/D, the fractional area of the deposit within which droplets land uncooled and coalesce into a lava pond.

	n =	30	100	300	1000	3000	10000
	u_g =	12.5	20.1	33.9	61.6	106.0	193.5
	D =	0.60	1.55	4.4	15	43	144
V/L = 0.15	Λ =	3.63	15.1	72	435	2210	13500
	F =	0.9940	0.9903	0.9840	0.9702	0.9488	0.9060
V/L = 0.30	Λ =	1.80	7.5	36	217	1110	6740
	F =	0.9970	0.9952	0.9918	0.9851	0.9744	0.9532
V/L = 1.00	Λ =	0.54	2.3	11	65	332	2020
	F =	0.9991	0.9985	0.9975	0.9955	0.9923	0.9860
V/L = 3.00	Λ =	0.18	0.75	4	22	111	674
	F =	0.9997	0.9995	0.9992	0.9985	0.9974	0.9953

Table 3. For 6 released magma gas contents n in ppm and 3 magma discharge rates from a point source vent V in m^3 s^{-1}, values are given for the distance Λ as defined in Table 2. For each n the gas eruption speed u_g in m s^{-1} and maximum droplet range D in km are given. For each Λ is given the value of F = $([D-Λ]/D)^2$, the fractional area of the deposit within which droplets land uncooled and coalesce into a lava pond.

	n =	30	100	300	1000	3000	10000
	u_g =	12.5	20.1	33.9	61.6	106.0	193.5
	D =	0.60	1.55	4.4	15	43	144
V = 3 x 10^3	Λ =	0.129	1.38	18.9	374	5640	114300
	F =	0.9996	0.9982	0.9914	0.9495	0.7560	0.0426
V = 1 x 10^4	Λ =	0.039	0.42	5.7	112	1690	34300
	F =	0.9998	0.9994	0.9974	0.9847	0.9231	0.5805
V = 3 x 10^4	Λ =	0.013	0.14	1.9	37	564	11430
	F =	0.9999	0.9998	0.9992	0.9948	0.9740	0.8475